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Errors in the NCEP/NCAR Reanalysis-1 air temperature data in the Arctic between 1997 and 2004, and a post processing correction

by

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Abstract

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Discrepancies are found between the air temperature data from the NCEP Reanalysis-1 product and the observation based IABP product beginning in the late-1990s in the Arctic region. Evidence points to an error in the incoming data stream for skin temperature used in the NCEP reanalysis. A comparison with long-term weather stations shows a warm bias, most prominent during the winter months. A correction was applied to the 2 m air temperature field to remove the bias. Significant improvements were made to the NCEP data, however, improvements varied spatially, and a monthly correlation analysis between observations and uncorrected and corrected data showed that, overall, the summer months (Jul-Aug) are better left uncorrected.

Résumé

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Des divergences ont été trouvées entre la température de l'air produite par les réanalyses-1 de NCEP et celle produite par les données d'observation de IABP à partir de la fin des années 1990 dans la région arctique. L'erreur semble venir du traitement des données utilisées dans le calcul de la température de peau dans les réanalyses NCEP. Une comparaison avec des stations météorologiques de longue durée montre un biais chaud, surtout visible durant les mois d'hiver. Une correction a été appliquée au champ de température à 2 m pour retirer le biais. Des améliorations notables ont ainsi été apportés aux données NCEP. Cependant, ces améliorations varient spatialement et une analyse de corrélation mensuel entre les observations et les données corrigées et non-corrigées montre que les mois d'été (Juillet-Aout) sont meilleurs sans la correction.

1 Introduction

Atmospheric reanalysis products are derived by assimilating observations from buoys and meteorological stations (among others) into an atmospheric model. These products are therefore dependent on high quality data and high-resolution coverage, but usually suffer from lack of both in the high Arctic (and the high latitudes in general). Moreover, as these products are based on complex automated systems, any changes or errors in the data streams feeding into the assimilative models can have unexpected results and can be difficult to spot.

Atmospheric reanalysis products are an important data set for climate studies (eg. Serreze et al., 2003; Overland and Wang, 2005; Lindsay and Zhang 2005), and they provide forcing for ocean and sea-ice models. Errors in the reanalysis products will lead to errors in the model results and thus it is important to detect and quantify systematic errors.

Observations show that the Arctic has experienced significant warming over the last 30 years (Serreze et al., 2000; Comiso, 2003); however, some reanalysis products emphasize this warming more than others. Biases in the NCEP/NCAR (National Centers for Environmental Prediction/National Center for Atmospheric Research) Reanalysis-1 product (hereafter, "NCEP-R1"; Kalnay et al., 1996) were previously reported by Large and Yeager (2004) and Hunke and Holland (2007), and are known to cause problems for both Arctic and global ocean-ice models. Here, we report on an error in the NCEP-R1 air temperature data (also present in NCEP-R2), which over-emphasizes the warming of the Arctic between 1997 and 2004. A correction is applied to the NCEP-R1 2 m air temperature field in the arctic region, and validated using observations from meteorological stations.

2 The Error

Figure 1 compares the average air temperature over the Arctic (north of 70°N) from various products: NCEP-R1, CORE (derived from NCEP-R1; Large and Yeager, 2004), ECMWF (European Centre for Multi-range Forecast), and the observation-based IABP (International Arctic Buoy Program, Rigor et al., 2000). These time series were smoothed with a three-year boxcar filter. Beginning in the late-1990s the NCEP-R1 and CORE time series show a significant warming trend that is not present in either the ECMWF or the IABP data.

A comparison between the NCEP-R1 data and observations from meteorological stations (Bekryaev et al., 2010) at Resolute, in the Canadian Arctic Archipelago, and Alert, on the north coast of Ellesmere Island (refer to figure 2 for station locations), revealed an error in the NCEP-R1 surface skin temperature (SST), surface air temperature (SAT, sigma=0.995), and 2 m air temperature (2mAT) fields at these

locations.

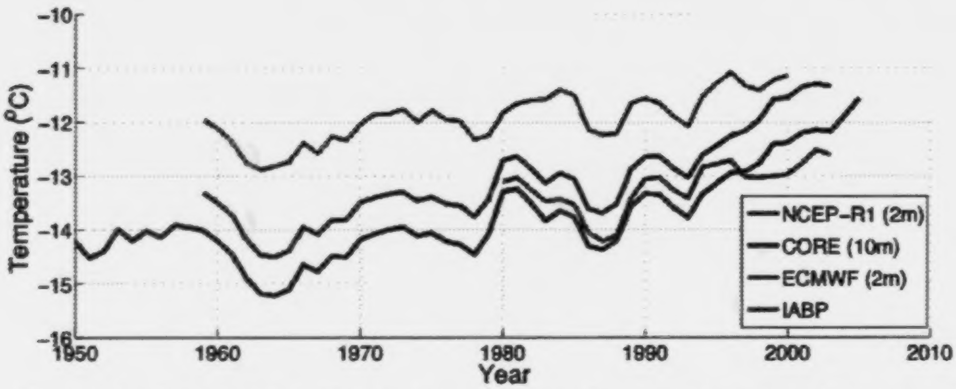

Figure 1: Time series of air temperature from various products, spatially averaged over the ocean region north of 70°N and low-passed with a three year running window.

Figure 2: Locations of meteorological stations. Station name and number are in reference to the data set provided by Igor Polyakov (International Arctic Research Center; pers. comm. 2010).

Starting in June 1997, and continuing until 2004 at Resolute, and until 2001 at Alert, the SST remains fixed at approximately -3°C and a there is a drastic change in the seasonal cycles of SAT, and 2mAT (Fig 3). Annual minimums of SAT and 2mAT are approximately 10°C higher than before 1997, introducing a warm winter bias. The average winter (Jan-Mar) temperature for Resolute increases from -33±1°C (between 1990 and 1996) to -22±4°C (between 1997 and 2004), and increases from -34±1°C to -24±1°C (between 1997 and 2001) at Alert. There is no significant change in the annual maximum and mean summer (Jul-Sep) temperatures.

After the error was detected and reported, a description of the error was posted on the NCEP problem list: "Polar temperatures shift 1998-2004. Different sea-ice analyses were used in that period, and it appears in some cases those analyses disagreed with the (reanalysis) model as to whether a given point was land or ocean, especially in the Arctic. New analyses used starting 2004 corrected the problem. So, skin temperatures and 2 m air temperatures (at least) were significantly higher at some polar region points for the period. NCEP plans no data replacement."

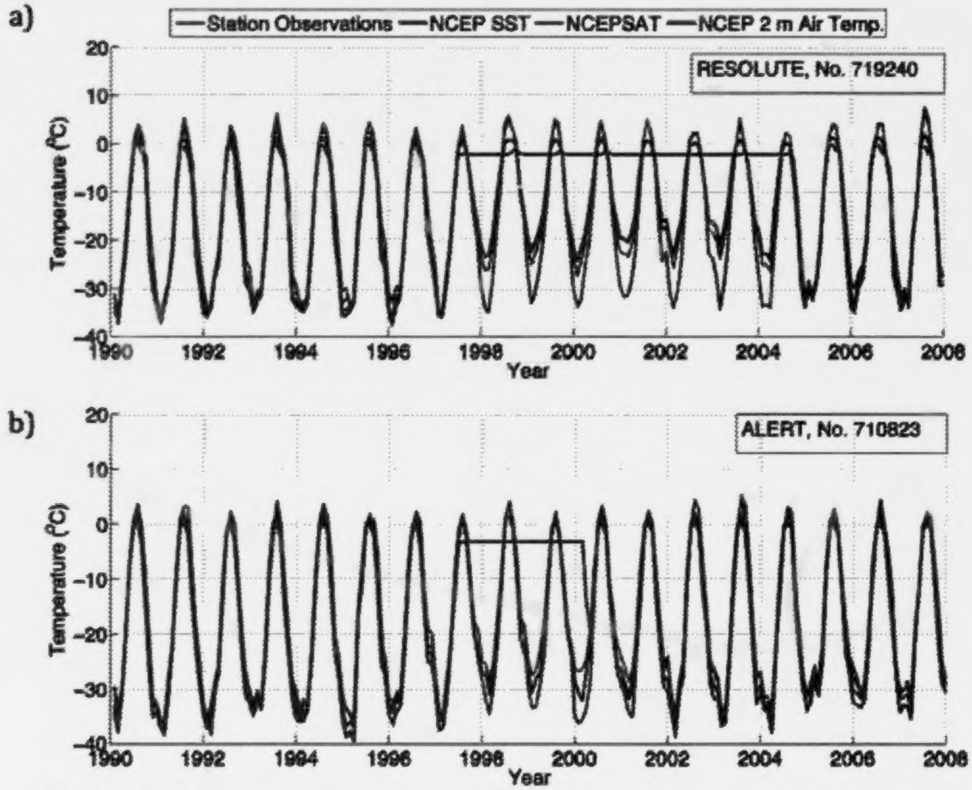

Figure 3: Monthly time series of station air temperature (observations) and NCEP-R1 SST, SAT and 2mAT at a)Resolute and b)Alert.

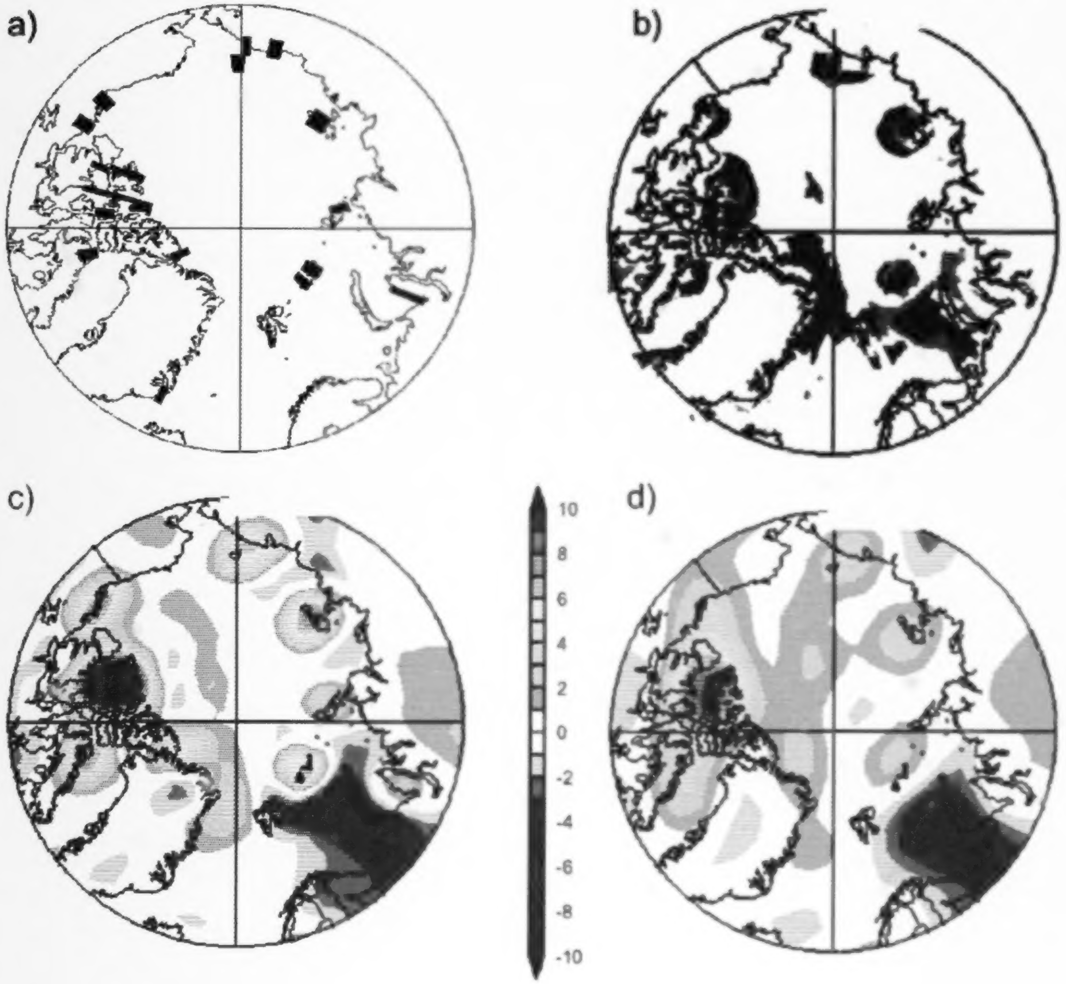

Figure 4: a)Grid points where ice concentration=1 before June, 1997 and =0 after, and winter (Jan-Mar, 1998) temperature anomalies for (b)SST, (c)SAT, and (d)1000 mb air temperature.

a)

b)

c)

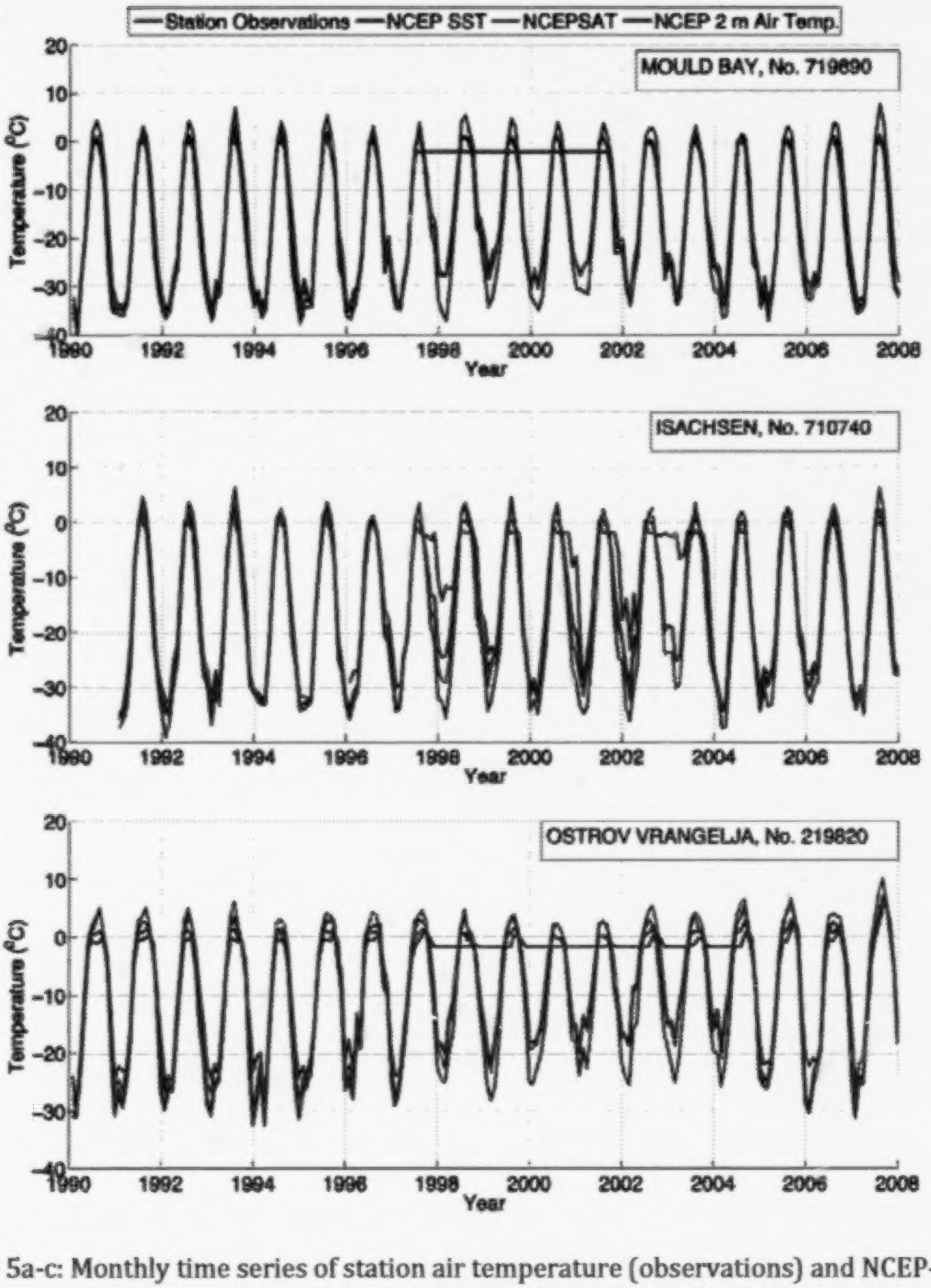

Figure 5a-c: Monthly time series of station air temperature (observations) and NCEP-R1 SST, SAT and 2mAT at a)Mould Bay (719890), b)Isachsen (710740) and c)Ostrov Vrangelja (219820).

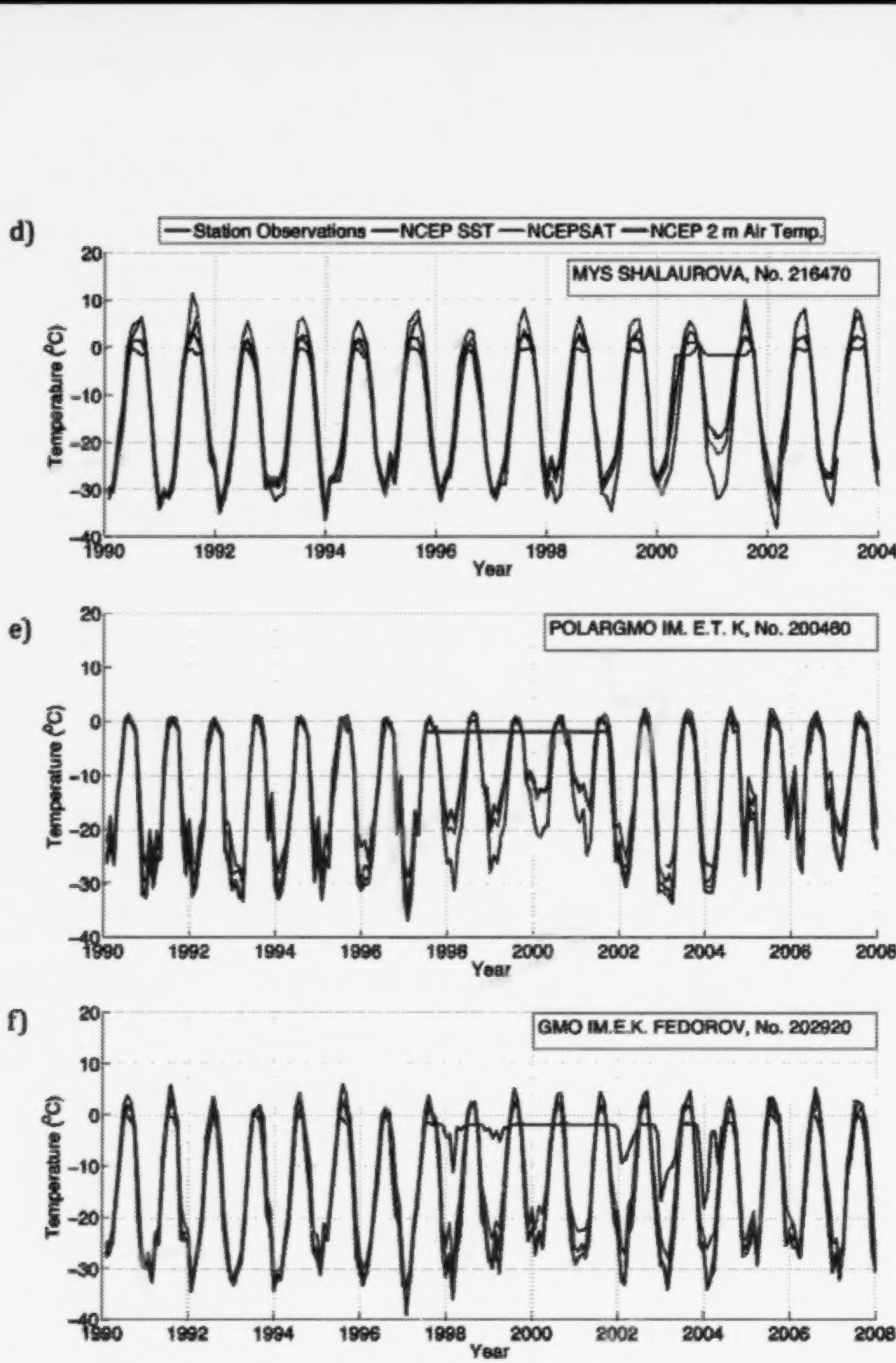

Figure 5 cont'd: Monthly time series of station air temperature (observations) and NCEP-R1 SST, SAT and 2mAT at d)Mys Shalaurova (216470), e)Polargmo IM. E.T. K (200460) and f)GMO IM.E.K. Fedorov (202920).

Thus, the error originated at points that the sea ice analyses considered to be land, but the model considered ocean. At these points, the sea ice analysis set the ice concentration to zero. Thus, the model considered the points to be ice-free and the SST, which is determined diagnostically as the temperature required to balance the fluxes at the surface, was set close to the freezing point of seawater.

Large positive errors occur during the winter months due to the large difference between the true skin temperature (-30°C to -35°C) and the model skin temperature (near the freezing point of seawater). Small negative errors occur during the summer months because the difference between the true skin temperature (near 0°C) and the model skin temperature is only a few degrees.

The grid points where the ice concentration changed from one to zero between early 1997 and 1998 are shown in figure 4a. Warm temperature anomalies are seen in the SST field associated with these grid points (Fig. 4b). With increasing model level or height above Earth's surface, the errors decrease in magnitude but increase in spatial extent (Fig. 4c-d).

Observations from six additional stations, chosen to coincide with the "hotspots" (refer to figure 2 for station locations), were also compared to the NCEP-R1 SST, SAT and 2mAT.

Although the SST is not necessarily fixed for the duration of the error period at every location (for example, station no. 202920 and 710740), an inconsistent seasonal cycle of SST, SAT and 2mAT is still prominent (Fig. 5a-f).

The error is also present in the Antarctic for the same time period, but affects far fewer points than in the Arctic. The correction discussed here was done for the Arctic region only.

3 Correction

A correction algorithm for the NCEP-R1 2mAT field was developed to give good results for at Resolute and Alert. The results were then validated against the data at the other six meteorological stations that was obtained after the algorithm was developed.

The algorithm is as follows. Data was removed in a 200 km radius from points corresponding to the SST "hotspots" and gaps were filled with data interpolated from a 1000 km radius using inverse distance weighting. Thus the correction applied to each grid point varies spatially and in time.

Figure 6 shows an example (February 1998) of the 2mAT field before and after the

correction was applied. The hotspots were removed leading to more reasonable values of temperature for the Arctic winter; however, some surrounding regions were unnecessarily altered and show as negative (warmer than original) values in the right panel of figure 6.

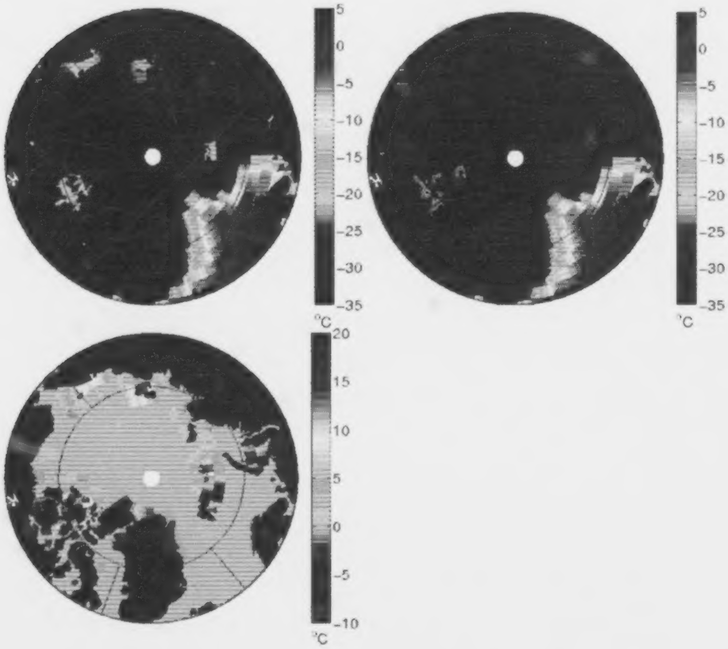

Figure 6: NCEP-R1 2mAT for February 1998, before (left) and after (centre) applying the correction, and the difference (uncorrected-corrected) between the two (right). Positive values (red) in the right panel represent cooling; negative values (blue) represent warming.

For six of the eight locations, the corrected time series of 2mAT are closer to observations than the uncorrected time series (Fig. 7), and the warm winter bias is removed (Fig. 8). The exceptions are station 219820 (Ostrov Vrangelja), where it appears the data is over-corrected (Fig. 7e), and station 202920 (GMO IM.E.K. Federov), where, despite a clear SST error, the errors in the uncorrected 2mAT are minimal (Fig. 7g and 8g).

Mean winter and summer temperatures prior to 1997 were compared to those during the error period, before and after the correction was applied, and pre-correction and post-correction biases were determined. Results are shown in Tables 1 and 2. Bolded

values are significantly different[1] than before 1997. For seven of the eight stations, the correction results in a decrease of the winter bias (Table 1), with the exception being GMO IM.E.K. Federov, where the mean temperature during the error period (before the correction) is not significantly different than the mean temperature prior to 1997.

However, at seven of the eight stations, the correction results in an increase in the summer bias (Table 2). Consequently, the correction was then applied in a second manner, that is, excluding the summer months (a partial correction). Then, a monthly correlation analysis between observations and the uncorrected (R_{nc}), fully corrected (R_{fc}), and partially corrected (R_{pc}) data was performed (Table 3).

Station 719240 (Resolute) can be considered our canonical example where the SST problem lasted over the full duration of the 1997-2004 period with no ambiguity. There, the correlation before the correction is high during the summer months and drops significantly during the winter months. The full correction largely improves the correlation during the winter season but significantly degrades the summer correlation.

At Station 710823 (Alert), where the error exists only between 1997 and 2001, the correlation analysis provides a less clear picture. The lowest correlations before the correction are seen during December, January and August. The correction improves the correlation for these months, but results in a decrease in correlation for May, June, July and October. August and September were only marginally improved.

For station 719890 (Mould Bay), the error period is long enough and unambiguous enough that the results are similar to Resolute with a decrease in the correlation for the summer months (in this case, including June).

At Station 710740 (Isachsen), the SST problem is not as apparent as the previous stations, although it still looks a bit suspicious (winter 1997-1998 and 2002-2003). However the correction improves (although sometimes only marginally) the correlation for all months except March.

Station 219820 (Ostro Vrangelia) is also similar to Resolute, with the exception that the correlation for August is slightly degraded.

Station 216470 (Mys Shalaurova) is similar to Isachsen with an ambiguous SST error, but the correction improved the correlation for all months except August. The improvement at Isachsen and Mys Shalaurova is likely due to the large spatial correlation scale present there.

At Station 200460 (Polargmo), correlation before correction drops close to zero (sometimes negative values) from May to August, and thus the correction improves the

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[1] Two values, $a \pm \Delta a$ and $b \pm \Delta b$, are significantly different if $\frac{|a-b|}{\sqrt{\Delta a^2 + \Delta b^2}} > 1$.

summer month as well as the winter months. The exception here is found during the fall where the correlation is better before the correction is applied.

Finally, at Station 202920 (GMO IM. E.K. Fedorov), where the initial errors minimal, the correction degrades the correlation for 7 of the 12 months, despite the clear SST problem.

From Figures 6, 7 and 8, it is apparent that the SST problem does not necessarily coincide with a problem in 2mAT. Station 202920 is a good example of this. Therefore, the correction can only improve the temperature and its correlation for such cases if the local spatial correlation scale is large enough (assuming the NCEP reanalysis is otherwise acceptable), as it did for Isachen and Mys Shalaurova. It appears this is not the case for station 202920.

Other problems are introduced by the correction procedure. At station 219820, Ostro Vrangelja, for instance, the corrected temperature is negatively biased during the cold months, despite improving the correlation overall. There, the spatial correlation must be large, but some local phenomena results in temperatures that are warmer than the surrounding area during the winter. Also, the spatial correlation seems to vary with time. At station 216470, Mys Shalaurova, the corrected summer temperature is positively biased between 1997-2000 but is on track from 2001 to 2004.

The correlation coefficients were averaged over the 12 months for each station to determine which correction method (full correction or partial correction) gave the best result, that is, produced the highest correlation to observations overall (Table 3). Results are plotted on figure 9. A '1' indicates that a full correction is best, and a '2' indicates that the partial correction (excluding the summer) is best. At three stations, a full correction resulted in the highest correlation, and for the other five stations, the partial correction resulted in the highest correlation. Note that, averaged over all months, correlation was always lowest for the uncorrected data.

Despite some deficiencies found with the correlation analysis or the quantitative assessment of the monthly cycles, the correction is important in restoring cold temperatures at key locations around the Arctic Ocean, and the exaggerated warming trend present in the NCEP-R1 2 m air temperature data is significantly reduced (Fig. 10).

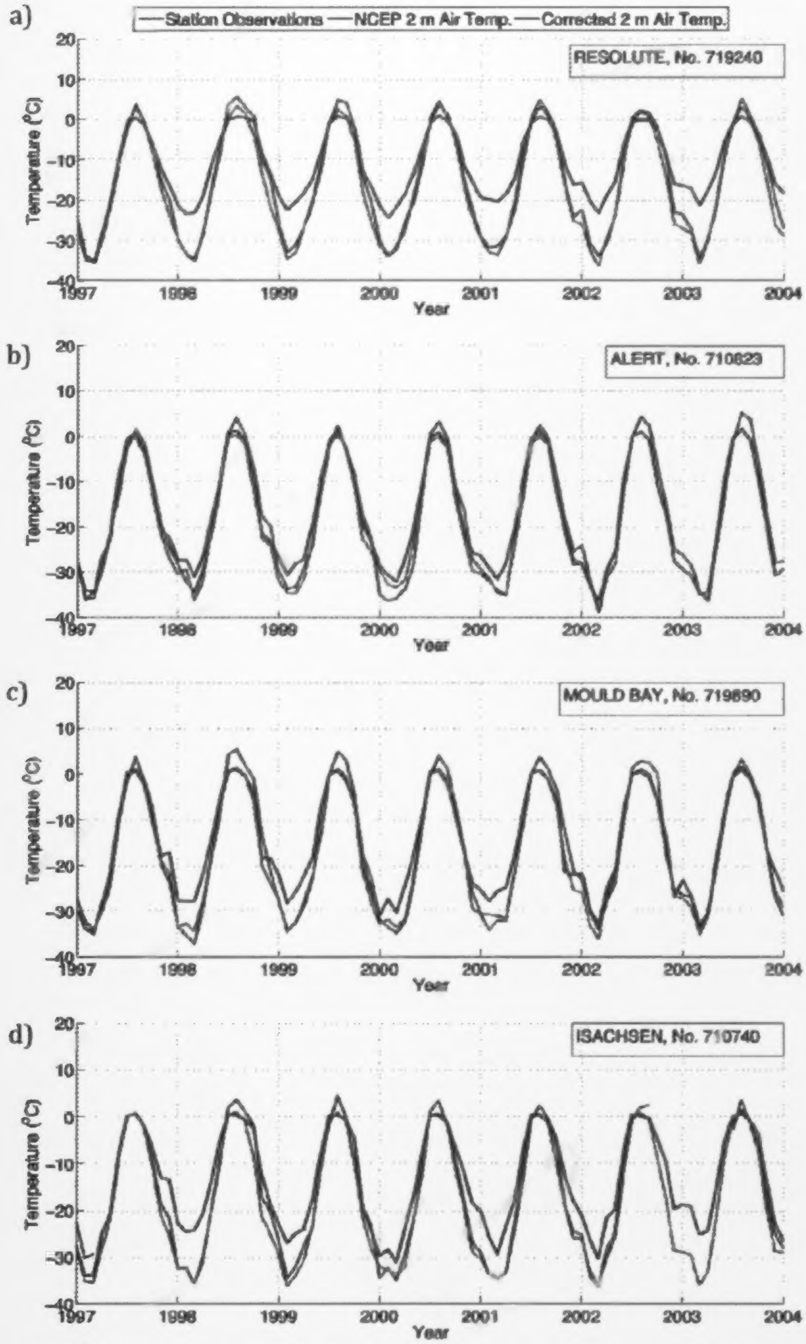


Figure 7: Monthly time series of station air temperature, with corrected and uncorrected NCEP-R1 2mAT at a)Resolute (719240), b)Alert (710823), c)Mould Bay (719890), and d)Isachsen (710740).

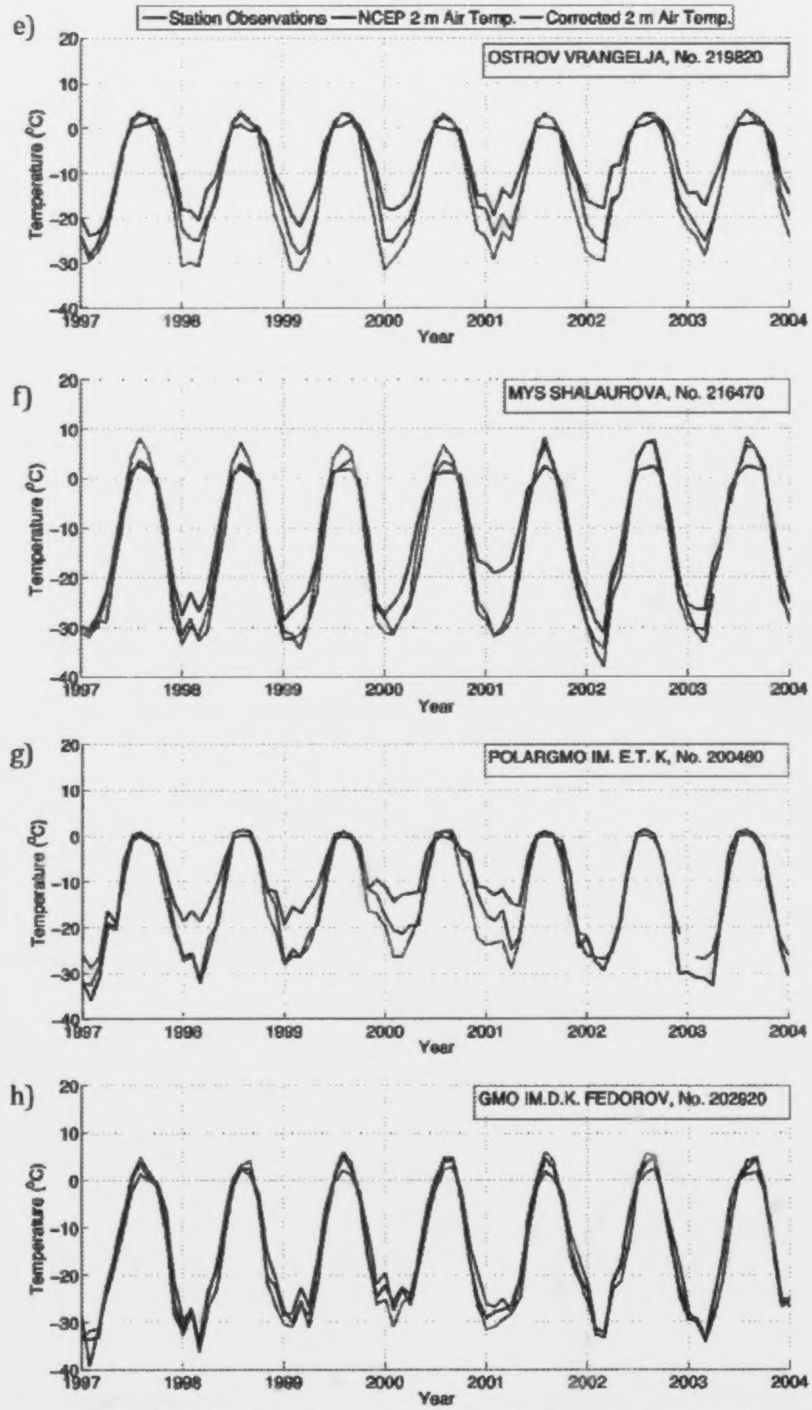


Figure 7 cont'd: Monthly time series of station air temperature, with corrected and uncorrected NCEP-R1 2mAT at e)Ostrov Vrangelja (219820), f)Mys Shalaurova

(216470), g)Polargmo IM. E.T. K (200460), and h)GMO IM. E.K. Fedorov (202920).

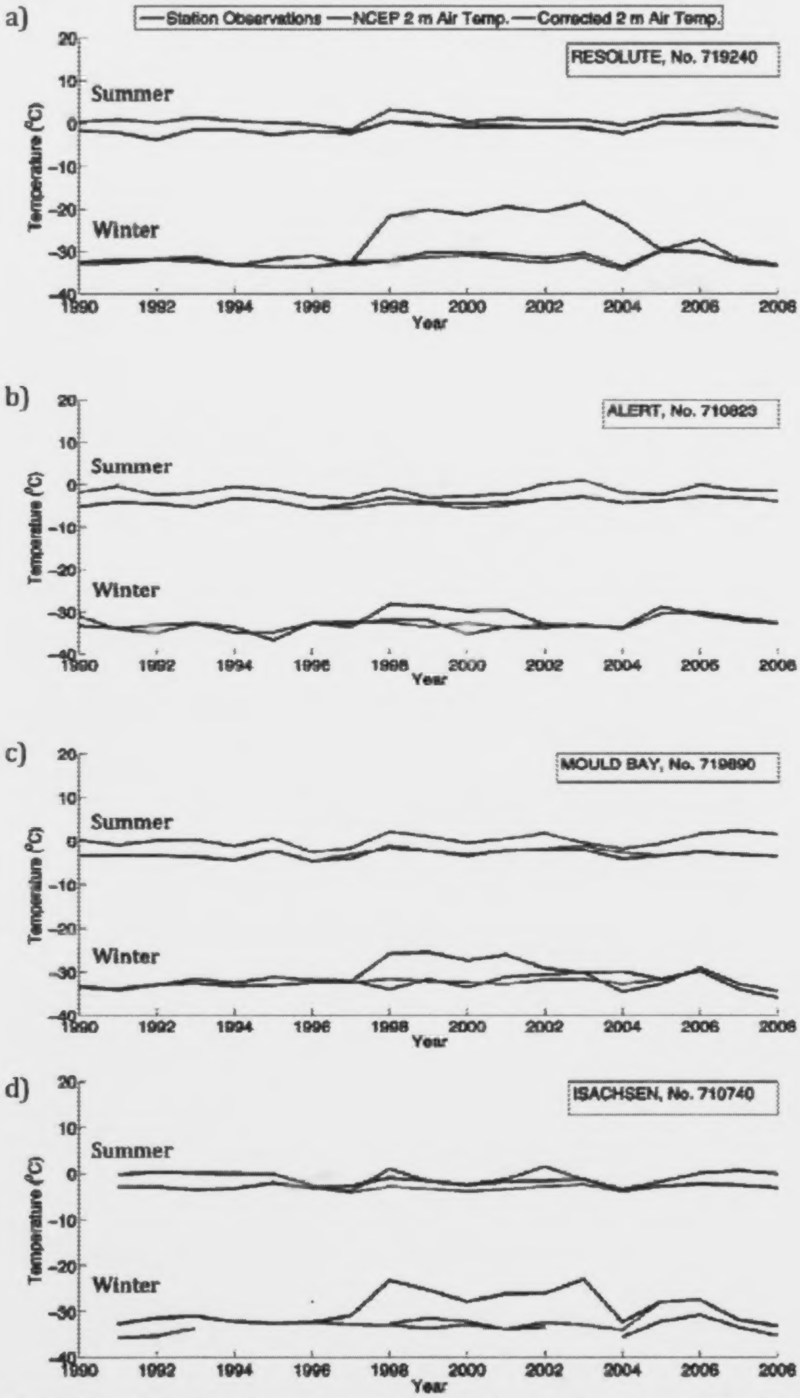


Figure 8: Winter (Jan-Mar) and summer (Jul-Sep) time series of station air temperature, with corrected and uncorrected NCEP-R1 2mAT at a)Resolute (719240), b)Alert

(710823), c)Mould Bay (719890), and d)Isachsen (710740).

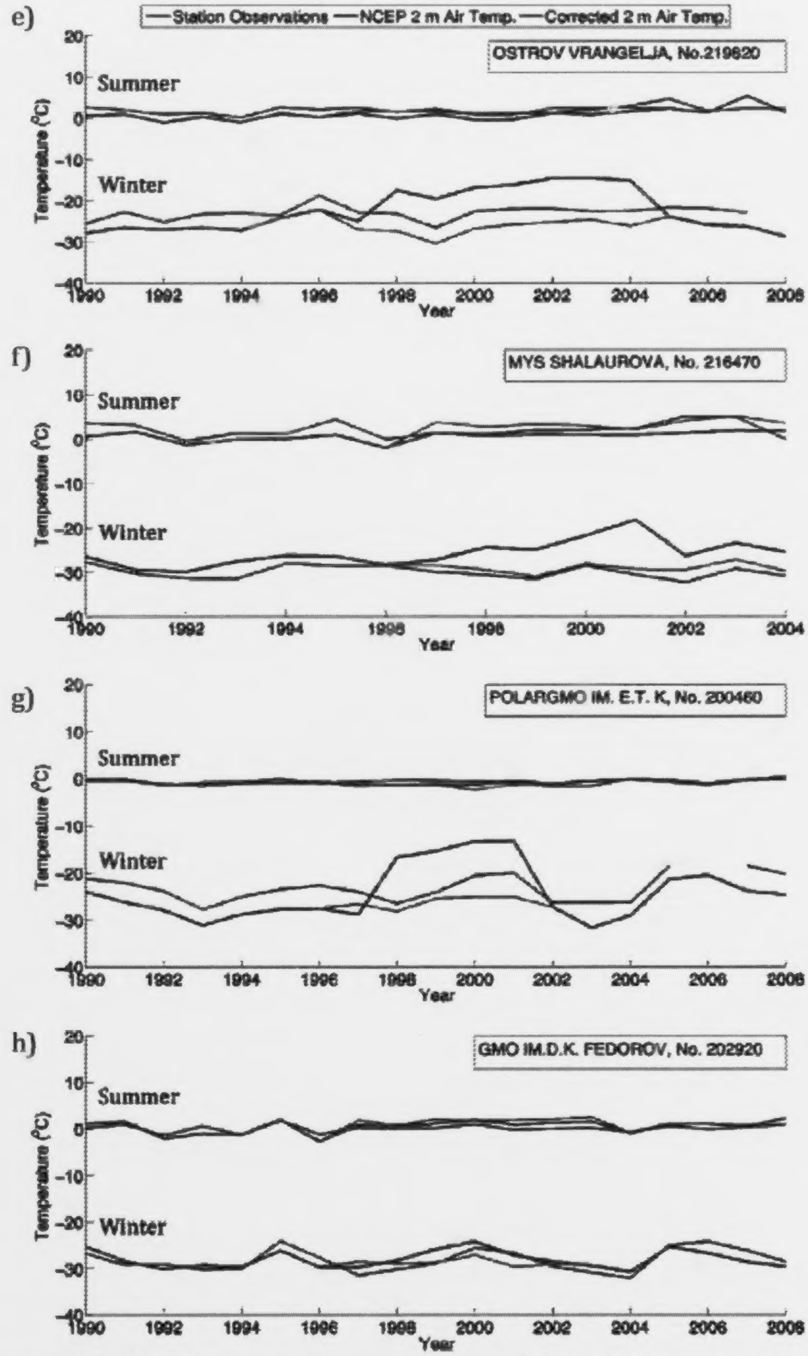


Figure 8 cont'd: Winter (Jan-Mar) and summer (Jul-Sep) time series of station air temperature, with corrected and uncorrected NCEP-R1 2mAT at e)Ostrov Vrangelja (219820), f)Mys Shalaurova (216470), g)Polargmo IM. E.T. K (200460), and h)GMO IM.

E.K. Fedorov (202920).

	NCEP-R1, Pre-1997 (std dev), °C	NCEP-R1, Pre-correction, 1997-2004 (std dev), °C	Post-correction, 1997-2004 (std dev), °C	Pre Correction Bias	Post Correction Bias
719240 Resolute	-32.85 (0.69)	**-22.27 (4.43)**	-32.17 (1.07)	10.57 (5.12)	⇓ 0.68 (1.75)
710823 Alert	-33.66 (1.43)	-31.26 (2.37)	-33.08 (0.56)	2.40 (3.80)	⇓ 0.58 (1.99)
719890 Mould Bay	-33.04 (0.53)	**-28.27 (2.47)**	**-32.18 (0.49)**	4.78 (3.00)	⇓ 0.86 (1.02)
710740 Isachsen	-31.86 (0.75)	**-26.45 (2.99)**	-32.54 (1.97)	5.41 (3.74)	⇓ 0.68 (2.72)
219820 Ostrov Vrangelja	-25.88 (2.00)	**-17.39 (3.47)**	-26.64 (1.76)	8.50 (5.47)	⇓ 0.75 (3.76)
216470 Mys Shalaurova	-27.71 (1.49)	**-23.90 (2.87)**	-29.02 (1.17)	3.82 (4.36)	⇓ 1.31 (2.67)
200460 Polargmo IM. E.T. K	-27.57 (2.18)	21.86 (7.95)	-27.26 (2.26)	5.71 (10.12)	⇓ 0.30 (4.44)
202920 GMO IM. E.K. Fedorov	-28.37 (1.88)	-27.98 (2.15)	-29.00 (1.03)	0.39 (4.03)	⇑ 0.64 (2.91)

Table 1: Mean winter (Jan-Mar) 2mAT (standard deviations in parentheses), and pre-correction and post-correction bias for each station. Bolded values are significantly different than the average temperatures before 1997.

	NCEP-R1, Pre-1997 (std dev), °C	NCEP-R1, Pre-correction, 1997-2004 (std dev), °C	Post-correction, 1997-2004 (std dev), °C	Pre Correction Bias	Post Correction Bias
719240 Resolute	-2.15 (0.85)	-1.07 (0.94)	-0.88 (0.92)	1.08 (1.80)	⇑ 1.27 (1.78)
710823 Alert	-4.51 (0.84)	-3.88 (0.68)	-4.44 (0.92)	0.63 (1.52)	⇓ 0.06 (1.76)
719890 Mould Bay	-3.50 (0.77)	-2.62 (1.07)	-2.25 (0.70)	0.88 (1.84)	⇑ 1.25 (1.47)
710740 Isachsen	-2.92 (0.47)	-2.00 (0.87)	-3.17 (0.59)	0.93 (1.34)	⇑ 0.25 (1.06)
219820 Ostrov Vrangelja	0.20 (0.82)	0.62 (0.78)	**1.77 (0.67)**	0.42 (1.61)	⇑ 1.56 (1.49)
216470 Mys Shalaurova	0.01 (1.24)	1.29 (0.46)	**3.53 (1.17)**	1.28 (1.67)	⇑ 3.52 (2.14)
200460 Polargmo IM. E.T. K	-0.85 (0.37)	-0.90 (0.45)	-1.19 (0.65)	0.05 (0.81)	⇑ 0.34 (1.01)
202920 GMO IM. E.K. Fedorov	-0.29 (1.87)	0.92 (0.87)	1.53 (1.08)	1.21 (2.74)	⇑ 1.82 (2.96)

Table 2: Mean summer (Jul-Sep) 2mAT (standard deviations in parentheses), and pre-correction and post-correction bias for each station. Bolded values are significantly different than the mean temperature before 1997.

	719240 Resolute			710823 Alert			719890 Mould Bay			710740 Isachsen		
	R_{nc}	R_{fc}	R_{pc}	R_{nc}	R_{fc}	R_{pc}	R_{nc}	R_{fc}	R_{pc}	R_{nc}	R_{fc}	R_{pc}
Jan	0.30	0.77	0.77	0.52	0.70	0.70	0.49	0.72	0.72	0.30	0.36	0.36
Feb	0.14	0.84	0.84	0.66	0.76	0.76	0.49	0.86	0.86	0.18	0.52	0.52
Mar	0.50	0.89	0.89	0.74	0.84	0.84	0.59	0.90	0.90	0.60	0.48	0.48
Apr	0.24	0.80	0.80	0.69	0.78	0.78	0.61	0.79	0.79	0.57	0.81	0.81
May	0.69	0.94	0.94	0.82	0.79	0.79	0.60	0.71	0.71	0.73	0.85	0.85
Jun	0.66	0.74	0.74	0.85	0.67	0.67	0.63	0.41	0.41	0.53	0.58	0.58
Jul	0.72	0.26	0.72	0.70	0.54	0.70	0.57	0.17	0.57	0.56	0.65	0.56
Aug	0.86	0.54	0.86	0.52	0.55	0.52	0.58	0.49	0.58	0.72	0.77	0.72
Sep	0.70	0.61	0.70	0.84	0.87	0.84	0.84	0.75	0.84	0.37	0.69	0.37
Oct	0.58	0.87	0.87	0.75	0.69	0.69	0.36	0.38	0.38	0.09	0.80	0.80
Nov	0.60	0.84	0.84	0.84	0.92	0.92	0.57	0.75	0.75	0.59	0.78	0.78
Dec	0.63	0.88	0.88	0.48	0.62	0.62	0.69	0.87	0.87	0.50	0.79	0.79
MEAN	0.55	0.75	**0.82**	0.70	0.73	**0.74**	0.59	0.65	**0.70**	0.48	**0.67**	0.64

	219820 Ostrov Vrangelja			216470 Mys Shalaurova			200460 Polargmo IM. E.T. K			202920 GMO IM. E.K. Fedorov		
	R_{nc}	R_{fc}	R_{pc}	R_{nc}	R_{fc}	R_{pc}	R_{nc}	R_{fc}	R_{pc}	R_{nc}	R_{fc}	R_{pc}
Jan	0.10	0.83	0.83	0.22	0.69	0.69	0.75	0.94	0.94	0.82	0.76	0.76
Feb	0.20	0.83	0.83	0.32	0.90	0.90	0.53	0.93	0.93	0.88	0.87	0.87
Mar	0.71	0.90	0.90	0.65	0.85	0.85	0.53	0.88	0.88	0.70	0.75	0.75
Apr	0.57	0.81	0.81	0.59	0.79	0.79	0.50	0.91	0.91	0.85	0.85	0.85
May	0.75	0.82	0.82	0.67	0.68	0.68	0.75	0.83	0.83	0.73	0.70	0.70
Jun	0.27	0.68	0.68	0.33	0.53	0.53	-0.01	0.33	0.33	0.52	0.62	0.62
Jul	0.81	0.31	0.81	0.34	0.62	0.34	-0.39	0.17	-0.39	0.44	0.44	0.44
Aug	0.76	0.46	0.76	0.87	0.49	0.87	0.01	0.21	0.01	0.83	0.75	0.83
Sep	0.76	0.75	0.76	0.66	0.87	0.66	0.69	0.54	0.69	0.78	0.76	0.78
Oct	0.86	0.76	0.76	0.78	0.80	0.80	0.79	0.80	0.80	0.97	0.96	0.96
Nov	0.62	0.84	0.84	0.46	0.86	0.86	0.77	0.76	0.76	0.69	0.74	0.74
Dec	0.36	0.90	0.90	0.71	0.88	0.88	0.59	0.83	0.83	0.92	0.88	0.88
MEAN	0.56	0.74	**0.81**	0.55	**0.75**	0.74	0.46	**0.68**	0.63	0.76	0.76	**0.77**

Table 3: Correlation coefficients calculated before (R_{nc}, no correction) and after the correction (R_{fc}, full correction; R_{pc}, partial correction) was made to the NCEP-R1 2mAT data. Shaded values indicate a decrease in correlation after the correction was applied.

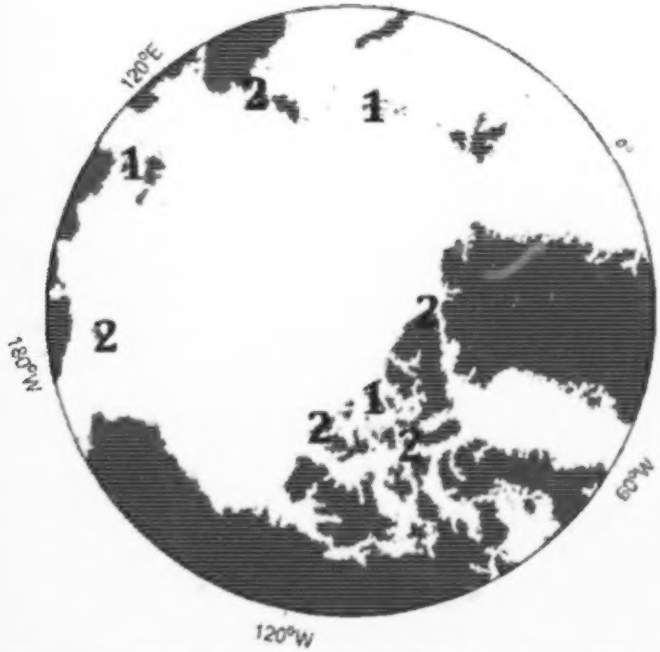
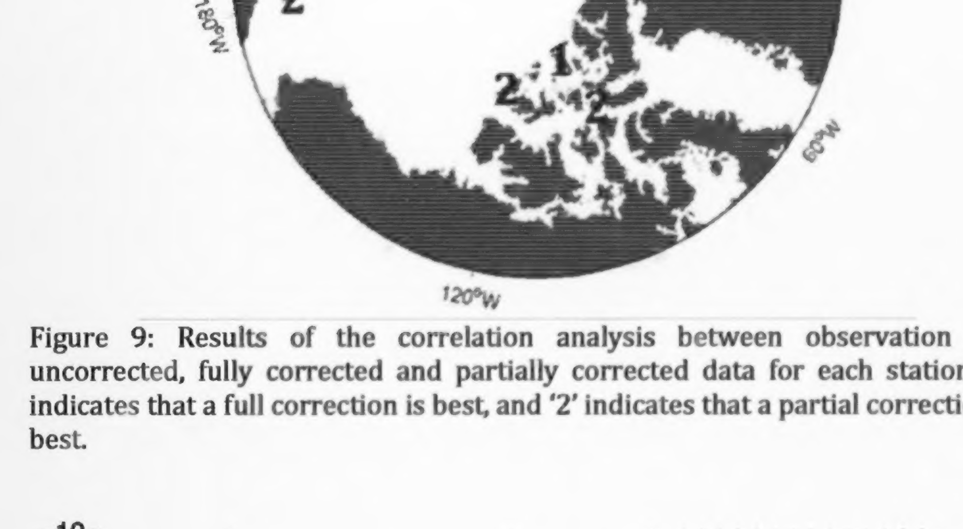


Figure 9: Results of the correlation analysis between observation and uncorrected, fully corrected and partially corrected data for each station: '1' indicates that a full correction is best, and '2' indicates that a partial correction is best.



ju9h8y8

Figure 10: Time series of 2 m air temperature, spatially averaged over the ocean region north of 70°N and low-passed with a 3 year running window, derived

from the uncorrected, fully corrected, and partially corrected NCEP-R1 data.

4 Conclusion

The exaggerated warming trend in the NCEP-R1 air temperature data over the arctic region during the period 1997-2004 originates from the misinterpretation of a new data stream for sea-ice concentration in the reanalysis model. A correction was successfully applied to the 2 m air temperature field, and validated using meteorological station observations throughout the arctic. The improvement was mostly seen in the winter season where the NCEP air temperature differed most from observed temperature. The correction however introduced a small warm summer bias. Results of a correlation analysis between observations and uncorrected and corrected data showed that July, August, and September are better left uncorrected.

The overall correction to the 2 m annual average Arctic air temperature is modest (north of 70°N, it would be at most 0.5°C during the 1997-2004 period). However the correction at the regional scale and particularly during the cold season is as much as 10°C. This has implications for ice-ocean models which use NCEP and derived products, such as CORE, for forcing. These models, if too close to their internal tipping points, may yield unrealistic downward trends in ice properties from which they may have difficulty recovering.

The errors in the sea-ice mask seem to exist between 1997 and 2004. Our correction introduces a modest and short reduction in the warming trend between these dates. As a consequence, the warming trend between 2004 and 2005 is larger than in the uncorrected data set.

Note that the same correction can also be applied to the CORE air temperature as this one is directly derived from the NCEP reanalysis product.

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